Statistical analysis of data on electricity generated from a small-capacity hydro power plant

Svilen Rachev[1], Milena Racheva[1], Lyubomir Dimitrov[1]
Technical University – Gabrovo [1], Republic of Bulgaria
srachev@tugab.bg

Abstract: *The widespread use of hydro power plants is well known. In addition to such plants that have been in operation for decades, there is currently an increased interest in the design and construction of new plants. In this regard, the accumulation of statistical data on the change in certain quantities and parameters for different periods of time and operating modes is important. On the other hand, subsequent processing of such accumulated data according to certain rules is possible. The main goal of this paper is statistical processing of data for a specific hydro power plant, in order to identify certain trends and prepare recommendations for improving activities.*

Keywords**:** *RENEWABLE ENERGY SOURCES, HYDROELECTRIC POWER GENERATION, GENERATORS, STATISTICAL ANALYSIS*

1. Introduction

The increased interest in renewable energy sources (RES) is driven by two key reasons – environmental sustainability and energy savings. Taking into account the rising and difficult to predict electricity prices, as well as the penalties associated with increasingly strict carbon emissions legislation, it is clear why in recent years the focus has been on the role of RES in reducing and/or stabilizing energy costs.

Sustainability is a multifaceted concept that is gaining increasing importance in our lives. The ways and practices to achieve it are green technologies – they can transform production and consumption patterns. European policies to promote renewable energy sources through legislative initiatives and financial instruments outline good prospects for hydro electric energy.

Water has been a traditional source of energy for centuries – look back to mills, fulling machines and other water-powered facilities. Harnessing its kinetic energy has been around for hundreds of years.

Hydro power plants (HPPs) convert the potential energy of water into electrical energy by driving a turbine. This type of power plant is relatively widespread in Bulgaria due to its mountainous terrain. The electrical energy produced by HPPs is included in the country's electricity balance.

Hydro power ranks first in the renewable energy sector and is expected to grow in importance worldwide over the next 10 years. Today, 70% of the world's renewable energy and 16% of total electricity are hydro power energy [1].

In Bulgaria, the share of electricity produced by HPPs is less than 20%. According to data from the Transmission System Operator (TSO), large HPPs generate approximately 14.37% of energy, and small ones – 2.66%. Currently, around 260 HPPs are operating in Bulgaria. In 2015, the total installed capacity of HPPs in Bulgaria was approximately 2,350 MW. By the way, it is believed that 2900 liters of water are needed to produce 1 kWh of electricity.

Hydro power is the world's largest source of green energy, overshadowing solar and wind. As such, hydro power enjoys a positive reputation in the media and in many academic papers. However, most of the 45,000 large dams worldwide are built for flood control, water storage, agricultural irrigation, fisheries, or recreation. Only about 25% of these facilities include hydro power.

As of 2019, the world's total renewable energy capacity stood at 2,351 GW, of which about half, or 1,172 GW, was hydro power. This includes both large dams and so-called run-of-river HPPs. Two-thirds of the world's major rivers are used for power generation. In Asia, dams construction is increasing, most of them enormous. This means deforestation, loss of land and wildlife, and changes in river patterns. As with other renewables, Asia is once again in the spotlight [2].

By the way, China has presented a plan to accelerate the implementation of artificial intelligence (AI) technologies in the energy sector. According to official documents, by 2027 the country should create an innovative system for integrating AI into the energy sector and achieve the first significant technological breakthroughs. By 2030, China intends to establish effective coordination between computing power and energy supply. It is planned to use AI technologies in the control of energy grids, the development of RES and nuclear power [1].

Experts emphasize that HPPs use only the kinetic energy of water. In fact, the power plants do not use any water resources, and after processing the appropriate amounts, they return to the riverbed. Hydro power engineers specify that the advantage of hydro power is not the price, but the zero carbon footprint of the process of its production.

For now, water remains among the most used RES in Bulgaria, and this is due to its wide application potential. Hydrological analyses show that Bulgaria is relatively poor in water resources. According to existing data, there are between 1600-2000 m^3 of water per capita per year. An advantage is the mountainous nature of a significant part of the territory. Thanks to this, the hydro potential, according to experts, reaches 26 billion kWh in an average runoff year. At the same time, the technically usable potential is within 57% of the theoretical one and is estimated at 15 billion kWh [3].

The existing technical and economic potential for the construction of large HPPs in Bulgaria is already almost exhausted or is unusable due to environmental protection considerations. This is one of the reasons for the increased investment interest in the construction of hydro power facilities with a maximum capacity of up to 10 MW, conditionally designated as small HPPs. Other reasons include the long period of operation of the facilities and the low costs associated with their production and maintenance, as well as the security of the investment, albeit with a relatively long payback period. Another advantage is the fact that small run-of-river HPPs do not use pre-reserved large volumes of water, thus avoiding the construction of a dam wall and the formation of a water storage basin.

The requirements regarding the quality of the electricity produced by small HPPs do not differ from the general requirements for other plants in the general energy system. In order to obtain maximum power from small HPPs, it is necessary for the turbines to operate at the maximum possible head, which requires, on the one hand, maintaining maximum volumes in the upper water storage basin (if any), and on the other hand, effective regulation of the hydro power units. With a relatively constant schedule of energy consumption, the production of electricity from small HPPs can easily be automated, thereby achieving higher efficiency.

2. Advantages and disadvantages of small hydro power plants

In addition to relatively low capital investment, small HPPs are also characterized by lower requirements regarding safety, automation, production cost, purchase price and personnel qualification. These characteristics predetermine the possibility of quickly starting construction and investing capital in the long term with minimal financial risk.

Small HPPs can be built on running waters, on drinking water pipes, on the walls of dams, as well as on some irrigation canals in the hydro-ameliorative system. They are suitable for users remote from the electricity grid. In addition, they are relatively easy to connect to the energy grid.

Another very important advantage of HPPs is that of all traditional energy sources, they start producing energy the fastest. It literally takes 2 to 5 minutes for a HPP to run and start generating energy. Hydro power plants, compared to other types of power plants, have much higher maneuverability. They start and stop quickly and can be loaded to their rated power in a short time, i.e. they can operate with power from zero to rated. Therefore, they have a special importance as a reserve and are very suitable for controlling the frequency and power in the electric supply system.

A disadvantage of small HPPs is their strong dependence on rainfall. As a result, they have a low rate of runoff utilization (up to 60%). Last but not least, their energy production must comply with the irrigation or water supply schedule when they are built in such systems.

Sometimes a very large length of the river is radically changed after the construction of a HPP. In recent years, many studies have come out that show that there is practically no dam that does not have an impact on fish. No fish passes have a 100% success rate. The other thing is that the water downstream changes – it becomes colder, with less oxygen or with variable quality, or with variable temperature, which, of course, affects all the organisms that are inside the river further downstream. And a very serious effect of HPPs is that downstream the sediments and the various chemical elements that are in the water are stopped by the dams and accordingly one of the very characteristic effects is that, for example, there is not enough sand to accumulate around the deltas of the rivers.

On the issue of HPPs – on the one hand, we need energy, on the other hand, these facilities must be built competently and not impact nature.

3. Potential for development of the hydro power plant energy branch

A number of expert analyses indicate that in Bulgaria there are about seven hundred sites with technological possibilities for the construction of small run-of-river HPPs. Most of them are located on mountain rivers, where the water quantities are larger and more constant over the years, despite the lower water pressure. Suitable sites are also provided by about one hundred water supply dams for the construction of sub-dam HPPs. However, the most attractive are small HPPs located on derivation systems. The reason is that when the relevant system is a water supply one, a constant water quantity and fixed hourly usability are ensured. There are also opportunities for installing hydro power equipment on water supply systems and wastewater treatment plants, which usually have a significant hydraulic head.

Hydro power plants use the most efficient technology for generating energy with high conversion efficiency and rapid recovery of the capital used to build the system. However, there is a need for small but significant improvements in technological development in many areas.

If the assessment of a given HPP shows that its condition is unacceptable, it is necessary to take the most appropriate actions to eliminate the problems. There are three options for this – repair and maintenance, modernization or reconstruction. When a given power plant reaches the age of 30-40 years, it is a good idea to carry out a study for possible modernization of the equipment and components. Advances in technology allow increasing the efficiency of turbines in many existing HPPs.

In many cases, the modernization of old HPPs is more expedient than the construction of new ones – the costs, environmental impact, social impacts and implementation period are relatively smaller. The renovated HPPs have increased power and efficiency. This includes completely new turbines, overhauled generators, and completely replaced hydraulic control and lubrication systems, which are modern and use less energy. They are more environmentally friendly and easier to maintain, which leads to fewer accidents.

Replacement of equipment (e.g. turbine impellers, generator windings, excitation systems, turbine governors, control panels, etc.) can provide higher efficiency, reliability and flexibility, as well as reduced operating costs. Overall, the potential for improvements in the rated power of existing HPPs is between 10 and 30%. It is financially justified to carry out modernization of hydro electric turbines, which will lead to an increase in efficiency by 4-8%. That is, it is reasonable to invest in modernization of existing facilities to produce more energy, rather than building new ones.

The main goal of power system control is to maintain a balance between production and consumption for a period of several seconds to years ahead. This requires ensuring the necessary reserves and system services from power plants in real-time control; short-term (hours, days) and medium-term (weeks, months) planning of the power system operation, as well as the development of long-term (years, decades) plans for the development of the power system.

The basic balancing and regulating capacities in the electric power system of Bulgaria are the large HPPs. During the spring high water freshet, increased electricity production from the HPPs is dispatched. During the summer season, the operation of the HPPs is entirely subordinate to the schedules for irrigation, drinking and industrial water supply, as well as to the ecological needs for moistening the riverbeds. Depending on the climatic conditions during the winter and autumn seasons, the HPPs operate to cover the electrical loads.

In addition to HPPs, priority production capacities include high-efficiency cogeneration and other RES (wind power plants, photovoltaics, biomass, etc.). The increase in the share of RES will strengthen the role of hydro electric power in managing fluctuations in wind power generation.

Investment in HPPs is not a ‘goldmine’ from yesterday. The beginning of the great interest in the hydro power business in Bulgaria dates back to 2002-2003, when the order for the construction of small HPPs was changed and a real boom in the issuance of construction permits occurred. The great interest in this business is dictated by the preferential purchase prices of this type of electricity from a renewable source. It is important that the hydrology in a country is relatively good. That is, there is a certain amount of water, and also high mountains, so the water can gain speed and strength. This way, more energy is obtained from less water, which increases efficiency. In case there is no high head, it can be created constructively through the water flow in an artificial way.

Nowadays, building a HPP costs a lot of money – from €0.5 million upwards. But once built, the plant receives preferential purchase prices for certain years ahead and a good profit is guaranteed.

In addition, the owner of the HPP simply receives the river terrain for eternal free use, since rivers are public state property and cannot be acquired by private individuals and companies. They are not even given out for concession. Thus, the owner of the HPP does not have to invest in land, like the owner of photovoltaics or wind generators, who must also change the purpose of the terrain.

The only annual cost paid to the state is the fee for the river water used, which is insignificant. For a plant producing about 0.5 MW and generating revenue from the sale of electricity during the year for about €100,000, the fee for the water used is only approximately €1,000. The preferential purchase prices are formed so that the investment for the HPP is returned over a period of 8-12 years, assuming that all requirements are met.

In summer, the operation of HPPs is limited due to the reduction of water in the rivers. However, many of them still work – they close the sluices, fill a water tank of a certain volume, including the pipe to the power plant, work for 1 hour, then collect water for 5 hours again. In fact, the power plants work on pulses (urges), which dry up the river not only between the water intake and the power plant building, but also do not release any water downstream. In summer, you can see many rivers with "working hours", which flow at intervals due to illegally operating HPPs.

According to some opinions, it is mandatory to immediately proceed with the preparation of an impact assessment of the already built HPPs on a national scale – from a hydrological, hydrotechnical and hydrobiological point of view, in order to establish what the effects are, what the benefits are and what the harms are. Only then will it be normal to carry out new design and construction with some benefits for society, and not just for the owners.

4. Describing of the considered hydro power plant

Pursuant to the Law on Energy from Renewable Sources (based on relevant acts of European legislation - directives and regulations, in force from 03.05.2011) a preferential price is set for the purchase of electrical energy produced from RES, including electrical energy, produced by HPPs with a total installed capacity of up to 10 MW. Hydro power plants with an installed capacity greater than 10 MW are not treated as RES, because other phenomena occur with them – e.g. change of the local climate in the presence of dams, etc. [4].

The Tazha HPP in question, with an installed capacity of 4.9 MW, was built to produce electricity and is a source of revenue for National Electric Company JSC, Bulgaria [5].

With its carbon-neutral energy production from one of the key renewable sources – water, National Electric Company JSC contributes to the achievement of the ambitious goals of Bulgaria and the European Union to achieve climate neutrality. With the energy produced by the HPPs, National Electric Company JSC is the largest producer of electricity from RES in Bulgaria.

National Electric Company JSC owns 31 hydro power plants (28 HPPs and 3 pumped storage hydro power plants, PSHPPs) with a total installed capacity of 2 737 MW in turbine mode and 931 MW in pumped storage mode. Before the privatization of HPPs in Bulgaria began in 2000, National Electric Company JSC owned a total of 73 HPPs. It turns out that HPPs are a very sought-after commodity on the market.

National Electric Company JSC plays a crucial role in ensuring the country's electricity security. Large HPPs play a significant role in the control of the electricity system. They are the main regulating capacities in Bulgaria. They balance the operation of the only nuclear power plant (NPP) and thermal power plants (TPPs) to date the variable loads of solar and wind power plants, as well as household consumers. Their main advantages are flexibility in system control and reliable mastery of peak load fluctuations, security and speed in replacing emergency shutdown capacities, primary and secondary frequency and exchange capacity regulation, and voltage regulation.

With the capacities from HPPs, National Electric Company JSC actively participates in the regulated, free and balancing markets and in the control and regulation of the energy system of Bulgaria. With energy from HPPs, National Electric Company JSC guarantees on the regulated market the security of supplies to end suppliers to meet the consumption of household and business customers connected at low voltage. On the free market, the company trades on all platforms of the Independent Bulgarian Energy Exchange (IBEX), founded in January 2014. In the balancing market, National Electric Company JSC-owned HPPs and PSHPPs are a major player with their fast-reacting capacities and wide coverage range.

With the development of the liberalized market, National Electric Company JSC's commitments as a public supplier of electricity for the regulated market will decrease, which will also allow for optimal use of the opportunities of HPPs and PSHPPs on the free market [5].

The Tazha HPP was built on the Tazha River, near the geographical center of Bulgaria. The idea for the construction of the plant was conceived by the Gramada Water Company, city of Gabrovo, Bulgaria. The stage of in-depth studies was before 1944. The construction itself began in 1945. The turbines were ordered from the Italian company SAN GIORGIO GENOVA-SESTRI. The construction of the Tazha HPP and its hydro technical facilities lasted from 1945 to 1951. In 1951, the water of the Tazha River was diverted and released through the diversion and the pressure pipeline. Water samples were successfully carried out. In December 1951, the turbines were put into operation for 72-hour tests, and on January 1, 1952, the power plant was put into operation. The generated electricity is transmitted by a 20 kV power line to the Kazanlak substation.

There are four water intakes – the Tazha River, the Babka River, the Dalboka River and the Svetishka Vada River. A water intakes coordinates (decimal): 42.688305, 25.038916; 42.683388, 25.038749; 42.688305, 25.038944; 42.674721, 25.054333. Water catchment elevation: Tazha River catchment at elevation 699.75 m; Dalboka River catchment at elevation 704.15 m; Babka River catchment at elevation 699.50 m; Svetishka Vada River catchment at elevation 699.0 m. Minimum water quantity after the water intake (liters/second): 438 – Tuzha River, 64 – Babka River, 69 – Dalboka River, 48 – Svetishka River.

The Tazha HPP has a water storage basin with an area of 25,458 m² and a net head of 150 m at an elevation of 534.5 m – Fig. 1. The Tazha HPP is a 4.9 MW power plant with three hydro groups. Annual electricity production: 10 000 – 15 000 MWh (1999 – 15 271 900 kWh; 2000 – 9 712 020 kWh; 2001 – 10 532 604 kWh). The plant has a permit to use water up to 4,000 liters/second from a water storage basin with a total volume of 40,000 m^3. The water storage basin and derivation channels of the Tazha HPP fall within the territory of the Central Balkan National Park [6].

Fig. 1 *Water storage basin of Tazha HPP.*

The technical basis of this HPP is as follows:

- ✓ own buildings (machine room, control room and substation);
- ✓ hydro facilities – pressure pipelines and channels – Fig. 2;
- ✓ energetic machines – hydro groups; control panel, measurement, protection, automation and signaling; indoor switchgear; transformers – 2 units; battery with rectifier for excitation of the generators**;**
- ✓ measuring instruments and tools.

The power part with hydro groups consists of:

- ✓ three Francis type horizontal axis turbines; one turbine has a design capacity of 2 540 kW, and the other two have a capacity of 1 265 kW each;
- ✓ three synchronous generators;
- ✓ two power transformers with rated power 5 600 kVA;
- ✓ indoor switchgear 20 kV.

Fig. 2 *Pressure pipeline of Tazha HPP.*

These three hydro groups are located indoors, in an machine room. The primary electrical circuit of the Tazha HPP is based on the ‘generator-transformer block’ principle.

Generator data:

- ➢ Generator 1: rated apparent power S_n = 3 440 kVA; rated voltage U_n = 6.3 kV; $\cos\varphi = 0.7$;
- ➢ Generator 2 and Generator 3: rated apparent power S_n = 1 720 kVA; rated voltage U_n = 6.3 kV; $\cos\varphi = 0.7$.

Each hydro group comprises a turbine, a synchronous generator, a line, a step-up transformer. Parallel work to the country's electric energy system is carried out on 20 kV buses to operator of the electric distribution grid EVN Bulgaria.

The excitation system of synchronous generators currently uses static thyristor exciters. Each exciter provides:

- ✓ automatic excitation supply when the generator is connected to the grid using the self-synchronization method, as a function of the frequency and phase of the electromotive force lag in the excitation winding;
- ✓ excitation supply during idle running of the generator when the exciter is powered from the own needs grid;
- ✓ maintaining a constant set excitation current with an accuracy of ±5% when the supply voltage fluctuates within the range of 70 to 110% of the rated and changes in the rotor temperature;
- ✓ local control of the set value of the excitation current in the range from the minimum to the rated excitation current;
- ✓ maintaining operability during short-term (no more than 60 s) changes in the supply voltage within the range of 50 to 140%;
- ✓ boosting excitation in case of emergency reduction of 10 to 15% of the rated value of the stator voltage;
- ✓ limitation of minimum and maximum excitation current.

In 2016, after an auction with offers held by National Electric Company JSC and selection of a contractor, turbine equipment was delivered for Hydro generator 2 of the Tazha HPP for rehabilitation purposes – polymer anti-friction self-lubricating materials, friction clutches, bronze pipe and stainless steel blanks for the reconstruction of the depreciated guiding apparatus of the hydro generator.

On September 18, 2024, a public procurement contract has been announced by National Electric Company JSC with the subject ‘Supply of a three-phase transformer 20/6.3 kV, 3.15 MVA for the Tazha Hydro power Plant for the purpose of replacing the transformer for Hydro generator 1’, which unfortunately, for a number of reasons, has been terminated on January 10, 2025. The problem is that any transformer operating at idle has losses that are greater if the transformer is over-rated, as is the case here.

Each power transformer is one of the most important electrical equipment in the power system and reducing power loss is of great economic importance for the power grid. Among the main directions in the improvement of power transformers is the reduction of losses.

No-load losses occur in the transformer core whenever the transformer is energized (even when its secondary winding is open, i.e. when it is not connected to any load). They are also called core losses and are constant. They consist of hysteresis losses and eddy current losses. No-load loss is a very important value, representing a significant amount of energy loss over the life of the transformer and unnecessary costs. Therefore, no-load losses should be minimized as much as possible.

No-load losses occur mainly due to the following reasons:

- ✓ core losses: the main component of no-load losses that occurs in the core is mainly due to hysteresis and eddy current losses;
- ✓ parasitic losses: although the proportion of these losses is relatively smaller, they contribute significantly to the total no-load loss; parasitic losses are created by stray eddy currents or confined magnetic fluxes and their impact on the total energy consumption can accumulate over time;
- ✓ flux distribution: uneven magnetic flux distribution can seriously affect core losses and magnetizing current.

Newly manufactured transformers have reduced components of all power losses, with particularly low no-load losses. Thanks to the development of magnetic materials, power losses are significantly reduced. Manufacturers choose high-quality and highly magnetic silicon steel sheets or even amorphous alloys as magnetic materials. This ensures uniform distribution of the magnetic flux and minimal noise during operation.

The no-load current is a basic parameter, and at no-load it is equal to the magnetizing current. It has a highly inductive nature and this is natural, since without consumption on the secondary side the transformer is one large choke (coil with a core). The no-load current as a value is 1-10% of the nominal current of a given transformer.

Reactive power losses in transformers also have two components: losses from the dissipation of the magnetic flux in the transformer ΔQ, depending on the square of the load current, and losses caused by the magnetization of the transformer ΔQμ, independent of the load current.

The last losses (magnetic) can be determined from the technical passport data using the no-load current i_{nl} and the rated apparent power S_{rated}:

$$\Delta Q_{\mu} = i_{nl} \frac{S_{rated}}{100}, kVAr \qquad (1)$$

The most commonly used static electronic electricity meters measure active and reactive power, as well as their sign, that is, the direction of energy flow. As a conclusion in this case – it is necessary to minimize all types of losses affecting monthly and annual energy payments.

What is the difference between reactive power and active power? Active power, also called real power, is the power that does the actual work. Reactive power comes from a variety of sources. Synchronous generators and capacitor banks are the main providers. Synchronous generators produce reactive power as part of their operation, while capacitors store it and release it when needed. Inductive loads, such as induction motors and transformers, also play a role by consuming reactive power.

Reactive power helps the grid operate more efficiently. When the grid does not have enough reactive power, it has difficulty transferring active power efficiently. This inefficiency leads to higher energy losses during power transmission.

Reactive power plays a critical role in electrical power transmission and distribution systems. It helps maintain voltage levels, ensuring the smooth flow of electrical power through the grid. Without it, there will be voltage instability and inefficient power transmission. With the increasing importance of RES, reactive power control becomes even more important for a stable and reliable electrical supply.

The production of active and reactive power by synchronous generators is regulated in several ways. Active power in synchronous generators is regulated by changing (increasing or decreasing) the mechanical power that the turbine supplies to the generator. Reactive power is regulated by changing the excitation current in the rotor – if the excitation current is greater than required, the generator supplies reactive power to the grid, if the excitation current is less than required, the generator consumes reactive power from the grid (operates in inductive load mode).

The production of active and reactive power is interrelated. When the synchronous generator is overloaded with active power, the generator voltage may drop if the excitation is not regulated properly, which requires correction of the excitation current. In principle, any rotating electrical machine is reversible and can be used as a generator or a motor. If the driving machine (turbine in this case) fails (shuts down), the generator continues to rotate as a synchronous motor, powered by the grid to which it is connected.

Renewable energy sources such as wind and solar are vital for a sustainable future. However, their variable nature creates challenges for grid stability. As renewable energy is increasingly connected to the grid, reactive power control becomes essential to maintain reliability and prevent power outages.

Table 1 below presents data on the generated and sold active and reactive energy for a period of two years. On Figure 3 and Figure 4 the changes in generated active and reactive energy by year are depicted.

Table 1: *Active and reactive energy sold.*

Month	Active electric energy sold, kWh	Reactive electric energy sold, kVArh
January I year	206 680	109 080
FebruaryI year	479 390	119 130
March I year	986 050	173 670
April I year	1 916 120	99 040
May I year	1 557 300	143 530
June I year	767 880	416 240
July I year	394 700	100 470
August I year	8 040	100 470
September I year	206 680	111 950
October I year	146 400	127 740
November I year	146 690	117 694
December I year	213 860	109 080
January II year	236 820	91 140
FebruaryII year	566 940	107 650
March II year	1 952 000	218 170
April II year	3 258 120	126 300
May II year	1 564 470	28 700
June II year	1 198 470	47 360
July II year	957 340	47 360
August II year	2 264 890	364 560
September II year	957 340	186 590
October II year	117 690	57 400
November II year	1 530 020	28 700
December II year	1 571 650	258 350

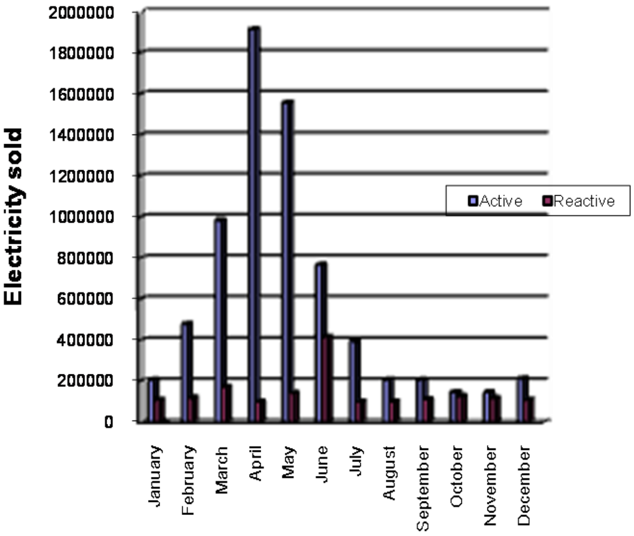

Fig. 3 *Chart of electricity sold by month for the first year, [kWh].*

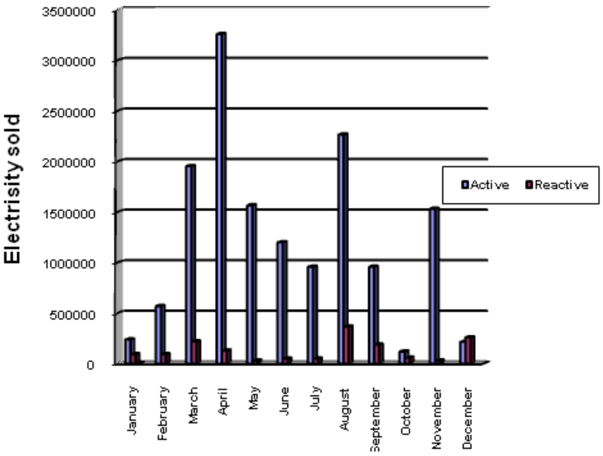

Fig. 4 *Chart of electricity sold by month for the second year, [kWh].*

The HPP in question has obviously produced and continues to produce reactive energy over the years, when necessary, according to the requests of the responsible operator.

5. Summary indicators for statistical processing of registered data

Mathematical statistics is applied as a tool facilitating the carry out of scientific research and the accumulation of data in the field of technology. Statistical methods are applied in a wide range of fields, such as the natural, social and engineering sciences, public administration, and business [7].

Cumulative data can generally be thought of as measurements of certain properties of objects selected from some large *population*. Information on certain characteristics of the elements is registered by *sampling*. Elements of the population are the so-called *statistical units* [4, 8, 9].

With the help of *samples* from measurements, some statistical indicators are determined, which are used to draw conclusions about some quantitative characteristics or parameters of the source *population* from which the sample was taken.

Position characteristics

There are several characteristics of the state of the empirical data population [9]. The most common is the *arithmetic mean* value. In short, the *arithmetic mean* is the value about which the entire empirical distribution can be "balanced".

For ungrouped data $x_1, x_2, ...x_n$ the *arithmetic mean* is,

$$\bar{x} = n^{-1}.\sum_{i=1}^{n} x_i \qquad i = 1,2,......n \tag{2}$$

As a characteristic of the position, a *geometric mean* value can also be used. In the case of sample volume n , the *geometric mean* is defined as:

$$\bar{\sigma} = \left(x_1 x_2 .....x_n\right)^{\frac{1}{n}} \tag{3}$$

Dispersion characteristics

One of the most commonly used characteristics of data dispersion is *arithmetic mean deviation δ.* For ungrouped data it is calculated this way:

$$\delta = \frac{\sum\left|x_i - \bar{x}\right|}{n} \tag{4}$$

Another characteristics of data dispersion is the *mean square deviation*. First, the square of this quantity, called the *variance*, is determined.

For a sample of ungrouped data, the *variance* is defined as:

$$s^2 = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1} \tag{5}$$

The *mean square deviation* is defined as the positive square root of the variance. For ungrouped data:

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}} \tag{6}$$

6. Results obtained

The data on the generated active and reactive energy for a period of 2 years are similar to another previously considered HPP, with the difference being about 5 times in installed capacity [4].

This population of statistical units, which in this case are empirical data for active and reactive energy (representing power multiplied by time duration), has been processed, which allows certain regularities to be established based on analysis. The tables that have been done, including calculation results, are implemented according to the rules of statistics [4, 8, 9, 10].

The so-called scattering measures are presented in tabular form [4, 8, 9], respectively *arithmetic mean, geometric mean, arithmetic mean deviation, mean square deviation*.

Table 2 and Table 3 present calculated summarizing indicators of the produced active electricity for the two years under consideration.

Table 2: *Statistical indicators, determined for the first year set for a month.*

Arithmetic mean $\bar{x}$, *kWh*	**Geometric mean $\bar{\sigma}$, *kWh***	**Arithmetic mean deviation *δ*, *kWh***	**Mean square deviation *s*, *kWh***
585 816	544 179	480 681	518 100

Table 3: *Statistical indicators, determined for the second year set for a month.*

Arithmetic mean $\bar{x}$, *kWh*	**Geometric mean $\bar{\sigma}$, *kWh***	**Arithmetic mean deviation *δ*, *kWh***	**Mean square deviation *s*, *kWh***
1 347 979	1 269 216	975 546	1 087 900

According to the data from Table 1, it is established that the arithmetic mean value of the plant's operation for the first year under consideration is 19,260 kWh per day, which means 3.95 (≈4.0) hours of operation per day. For the second year under consideration, the arithmetic mean value is 44,317 kWh per day, which means 9.08 (≈9.0) hours of operation per day.

7. Conclusions

After examining the HPP as a source of electricity and presenting the features of the activity of the Tazha HPP, the main goal has been achieved, namely the summarizing indicators for the plant's activity have been derived based on data for a two-year period.

Using statistics, scattering measures have been determined – arithmetic mean, geometric mean, arithmetic mean deviation, and mean square deviation.

The results obtained are of interest from an applied point of view in order to establish certain trends during relevant analyses.

It is worth noting that despite the installed capacity of 4.9 MW, according to the calculated statistical characteristics, the maximum value of the generated and, accordingly, delivered to the energy system and sold active power reached almost 0.6 MW for the first year under consideration and 1.35 MW for the second year. This raises the question of whether the business plan for the construction of such a plant, prepared before the investment and installation (construction), with any payback period, would have been implemented. In all cases, it is a question of invested own funds or funds obtained through a bank loan. In this regard, it can be pointed out that not all hydro groups will operate continuously, as some of them may be taken out for repairs, mainly due to problems with the turbines or generators (mainly in the bearings) or in the transmission mechanisms. The latter emphasizes the role of preventive maintenance in achieving the planned electricity production.

The following are important considerations, also mentioned at the beginning:

- ✓ The efficiency of small HPPs is significantly lower than that of large HPPs built after dams, as the former are highly dependent on the annual season and rainfall.
- ✓ Capital investments for the construction of small HPPs are relatively low and pay off relatively quickly.

Regardless of the already known inconveniences in the use of RES, the so-called ‘green energy’ and its storage for later use is set to be the basis of the sustainable energy of the future.

As with other sources of energy, the goal of RES is to generate energy at the least cost. However, adequate programs, investments and mechanisms are needed to encourage the further development of this production. The dynamic regulatory environment that has been observed in recent years and the introduction of restrictive measures have a significant negative effect on the financial situation of companies, worsen the competitiveness of hydroelectric power generation and prevent the implementation of new projects in the sector. In order to avoid the adverse consequences of this policy, which will most sensitively affect the price of energy for society, the creation of a predictable regulatory framework ensuring the sustainable development of the sector is an urgent priority.

Electricity use is constantly growing, and conventional sources are being depleted at a very rapid rate. One of the solutions to prevent the energy crisis is for people to start getting more energy from RES. In practice, several types of renewable energy are often used together to combine their advantages for maximum efficiency for each specific application. In addition, energy storage systems can be included.

8. Acknowledgments

The implementation of this paper is thanks to the support from: the Project BG16RFPR002-1.014-0005 Competence Center 'Intelligent Mechatronic, Eco- and Energy-Saving Systems and Technologies' financed by the Operational Program 'Science and Education for Intelligent Growth' of the European Regional Development Fund.

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